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EXPERIMENTAL INVESTIGATION  
OF HYPERSONIC AERODYNAMICS

Semi-Annual Research Report

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## Introduction

An extensive series of ballistic range tests are currently being conducted at the Ames Research Center. These tests are intended to investigate the hypersonic aerodynamic characteristics of two basic configurations, which are:

1. The blunt-cone Galileo probe which is scheduled to be launched in late 1989 and will enter the atmosphere of Jupiter in 1994.
2. A generic slender cone configuration to provide experimental aerodynamic data including good flow-field definition which computational aerodynamicists could use to validate their computer codes.

This progress report covering the period April - October 1987 presents some of the results obtained thus far in these investigations and discusses the work planned for the near future. All measurement values presented herein are expressed in the International System of Units; however, the English system of units was used for all principal measurements and calculations during the course of the investigations.

This work is being done under NASA Cooperative Agreement (Grant) No. NCC 2-475 for the Ames Research Center. The principal investigator is Peter F. Intrieri; the NASA Technical Officer for this grant is Dr. Gary T. Chapman of the Thermosciences Division, 229-3, Ames Research Center.

## Test Facilities

Two ballistic ranges at Ames Research Center are operational and both will be used in the present investigations. The facilities are the Hypervelocity Free Flight Aerodynamic Facility (HFFAF), and the Pressurized Ballistic Range (PBR). These facilities will be described briefly.

### Hypervelocity Free Flight Aerodynamic Facility

The test section of the HFFAF is 23 m long and has 16 orthogonal spark shadowgraph stations evenly spaced (1.52 m) over its length. This facility is used primarily for aerodynamic studies. Kerr-cell shutters are used to produce a sharp image of the model and its flow-field on the film. Four deformable-piston, light-gas guns, having bore diameters of 0.71, 1.27, 2.54, and 3.81 cm, are available for launching a model into free flight. Each of these guns can operate to muzzle velocities of about 9 km/sec.

Tests in this facility can be conducted from 1 atm to as low as 20  $\mu$ m Hg. The facility has an extremely low leak rate, about 10  $\mu$ m/minute. This allows for tests to be conducted in air or in any other nontoxic gas. Tests have been conducted in carbon dioxide, hydrogen, helium, krypton, and xenon.

### Pressurized Ballistic Range

The PBR is basically a large tank that can be pressurized or evacuated. It also is used mainly for aerodynamic studies. The test section is 62 m long and has 24 orthogonal spark shadowgraph stations irregularly spaced over its length. The station spacing ranges from 2.1 to 4.2 m. All of the optics are internal to the tank, which imposes a maximum model velocity of about 3.6 km/sec. At higher velocities, radiation from the gas cap around the model fogs the film, making readings of the model position and attitude impossible. This facility has some advantages over the HFFAF:

1. A much longer model trajectory is obtained (2.7 times).
2. Tests can be conducted above 1 atmosphere, currently to 6 atmos.
3. More detailed shadowgraphs are obtained, primarily because of the simpler internal optics system.

Testing in gases other than air in this facility is impractical because of the large physical volume of the tank.

## Galileo Investigations

The ballistic ranges at Ames have supported all of the United States' probe missions to other planets. These include the 1976 Viking Missions to Mars and the 1978 Pioneer Mission to Venus. These facilities are currently being used to support the Galileo Mission to Jupiter. The Galileo spacecraft consists of two major components: The orbiter, which is to orbit Jupiter numerous times while achieving close encounters with many of Jupiter's moons, and a probe, which is to enter and descend through the atmosphere of Jupiter. The probe, scheduled to enter the atmosphere of Jupiter in 1994, will make

in situ measurements as it descends through the atmosphere prior to its eventual destruction due to extreme external pressures.

Although some probe aerodynamics were obtained initially in exploratory tests to support early design studies (Ref. 1), more accurate aerodynamics are needed for support of the Atmosphere Structure Experiment, carried on board the probe.

#### Atmosphere Structure Experiment

The Atmosphere Structure Experiment is designed to determine the state properties (density, pressure, and temperature) of an unknown planetary atmosphere as functions of altitude from measurements made during the entry and descent of a probe. The experiment consists of a three-axis accelerometer, plus pressure and temperature sensors. After the probe slows down to subsonic Mach numbers, a parachute is deployed and the pressure and temperature sensors can make near-ambient measurements. However, during the high-speed portion of the trajectory, from an entry velocity of 47 km/sec to sonic speed, direct measurements are impractical. The temperature sensor would be burned up and dynamic pressure effects would render the pressure readings useless. The accelerometers alone must yield the state properties during this high-speed phase, and this in turn requires the precise knowledge of the probe aerodynamic characteristics, in particular drag and lift. These characteristics must be known accurately over a wide range of both Mach number and Reynolds number. The ballistic ranges at Ames have proven to be excellent facilities for obtaining this aerodynamic information over wide ranges of Mach number (0.5 - 20) and Reynolds number (250 -  $10^7$ ).

#### Galileo Data

The Galileo probe at entry into the Jovian atmosphere is shown in Fig. 1. It is basically a blunt 45 deg. cone. However, during the high-speed part of the entry, massive ablation takes place. As much as 40% of the vehicle mass at entry is expected to be ablated away, mostly in the nose region, and even the maximum diameter will be significantly decreased. Hence, tests must be conducted not only of the entry configuration but of hypothesized ablated configurations as well. (Sensors embedded in the heat shield will help to define the ablated shape during and after the actual entry.)

A large data bank was available for the Pioneer Venus probe. That configuration was similar to Galileo, as shown in Fig. 2. The nose, corner, and afterbody geometries are all slightly different, but as much use as possible is being made of all Pioneer Venus data to minimize the number of Galileo tests required.

Figure 3 shows some of the Galileo drag data obtained in the present investigation compared with available Pioneer Venus data at the same conditions of velocity and Reynolds number. Open symbols denote Pioneer Venus data and solid symbols are Galileo data. Not surprisingly, the Galileo data are not greatly different from those of Pioneer Venus; the Galileo data are approximately 3 percent lower than the Pioneer Venus data at the lower angles of attack. However, the differences are real and are important.

A 1% error in the knowledge of the probe drag coefficient becomes a 1% error in the density of the atmosphere of Jupiter at that point in the trajectory. This induces a similar error in the derived atmospheric pressure and often errors of many degrees Kelvin in temperature. The success of the Atmosphere Structure Experiment depends on the precise knowledge of the probe aerodynamics which is the driving reason for the many ballistic range tests required.

Ballistic range tests are currently planned to precisely define the drag characteristics of the Galileo probe at a velocity of about 4600 m/sec at Reynolds numbers (based on model diameter) from about 1 million to as low as possible, probably about 250. Current plans are to conduct tests at Reynolds numbers of  $10^6$ ,  $10^5$ ,  $10^4$ ,  $10^3$ , 500 and possibly 250, for which Pioneer Venus data exists for direct comparison. The importance of obtaining drag data at these various Reynolds numbers is evident in Figure 4, which shows the Pioneer Venus drag data (for zero angle of attack) down to a Reynolds number of about 250. The drag coefficient increases continuously below a Reynolds number of 1 million, but the increase becomes most dramatic below 1000 where the slip-flow and free-molecule-flow regimes are approached. Ballistic range tests of Pioneer Venus models at Reynolds numbers of 1000 and less proved to be difficult, but techniques were developed which led to successful tests. These same techniques will be used in the upcoming Galileo tests at these low Reynolds numbers. These high-speed tests will be conducted in the HFFAF. Model and sabot combinations have been designed and are being fabricated at the present time. The tests will begin when these models are built and the HFFAF and the guns are available for testing.

Ballistic range tests are also required to obtain drag data at Mach numbers of about 1 and 2 since the probe parachute will not be deployed until the probe slows down to subsonic Mach numbers near 0.8. All of these low Mach number tests will be conducted in the PBR. A few exploratory tests at these Mach numbers were conducted previously, as mentioned earlier, in support of early Galileo design studies. These tests will be re-analyzed using more sophisticated data reduction techniques to specifically obtain accurate drag data. However, several additional tests will probably be required to precisely define the drag characteristics in this Mach number range.

### Slender Cone Investigations

The extreme environment of hypersonic flight is difficult to achieve in most ground-based facilities, or when they can, as in the ballistic range, detailed information is difficult to obtain, particularly on complex configurations such as airplanes. Therefore, computation fluid dynamics (CFD) is going to play a more extensive role in designing hypersonic vehicles. However, these codes need experimental data to check the validity of the codes. This can be done on simpler generic bodies.

A series of ballistic range tests will be conducted using slender cones with various degrees of bluntness at Mach numbers between 15 and 20. The aerodynamic forces and moments will be determined and analyzed. To provide more detailed information concerning the flow field, small annular shock generators will be placed on the model. The embedded shock shapes plus the

bow shock shape will provide details concerning the state of the flow field air under these extreme hypersonic conditions. Information on the shear layer in the wake region will also be obtained (angle of free shear layer, etc.). All of these data will provide critical understanding and a data base for validation of CFD codes.

The basic configuration selected to be tested for this investigation is a 5 deg. half-angle cone. The base of the models will be hollowed out and/or bimetallic models will be used to make the models statically stable in flight. Model and sabot combinations are currently being designed and fabricated. The tests will be conducted in the HFFAF at speeds up to about 6 km/sec. In order to provide some experimental aerodynamic data on a slender cone configuration quickly (albeit not as slender as desired), it was decided to retrieve some old tests of a 10 deg. half-angle cone (Ref. 2) for more detailed analysis of the aerodynamic characteristics using more sophisticated data reduction codes which were not available at the time of the tests. The records of six of these tests at speeds of about 5 km/sec ( $M \approx 17$ ) have been retrieved from storage in a NASA warehouse, along with shadowgraph pictures showing details of the flow field about the models, and are currently being analyzed. These experimental data and shadowgraphs can be used in the interim by computational aerodynamicists to check the validity of their computer codes for this configuration until the 5 deg. half-angle cone tests are completed and the flights analyzed. These tests of the 5 deg. half-angle cones will commence in the HFFAF as soon as the models and sabots are built and the facility and guns are available for testing.

## Bibliography

1. Intrieri, P.F. and Kirk, D.B.: High-Speed Aerodynamics of Several Blunt-Cone Configurations. Journal of Spacecraft and Rockets, Volume 24, No. 2, pp. 127-132, March-April 1987.
2. Intrieri, P.F.; Kirk, D.B.; Chapman, G.T.; and Terry, J.E.: Ballistic Range Tests of Ablating and Nonablatating Slender Cones. AIAA Journal, Volume 8, No. 3, pp. 558-564, March 1970.

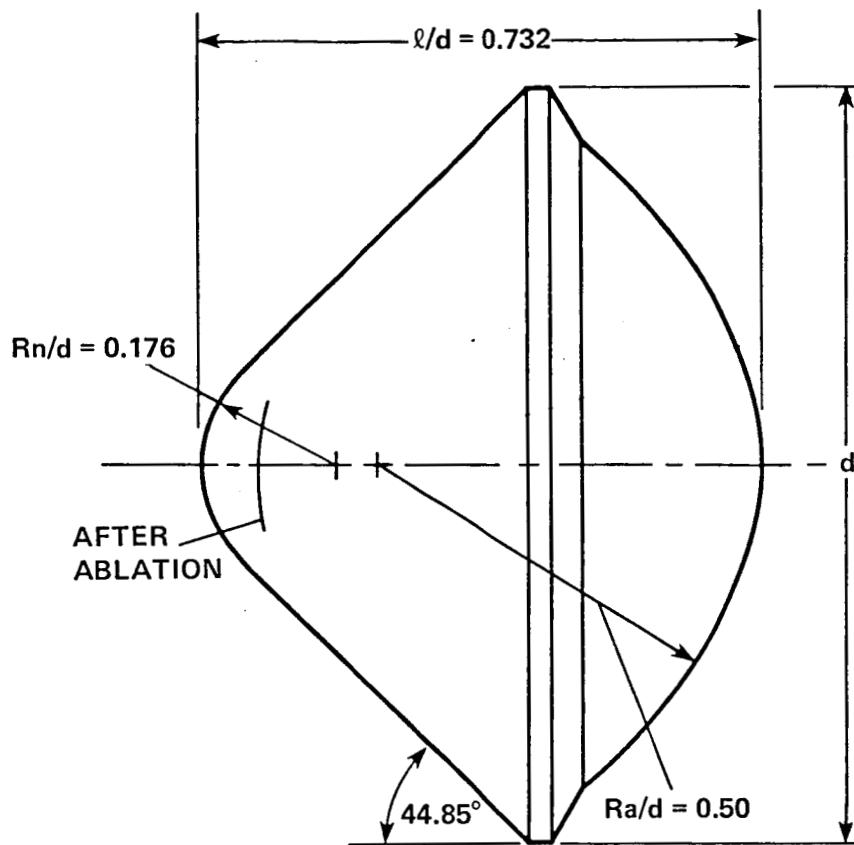


Figure 1. Galileo entry probe configuration



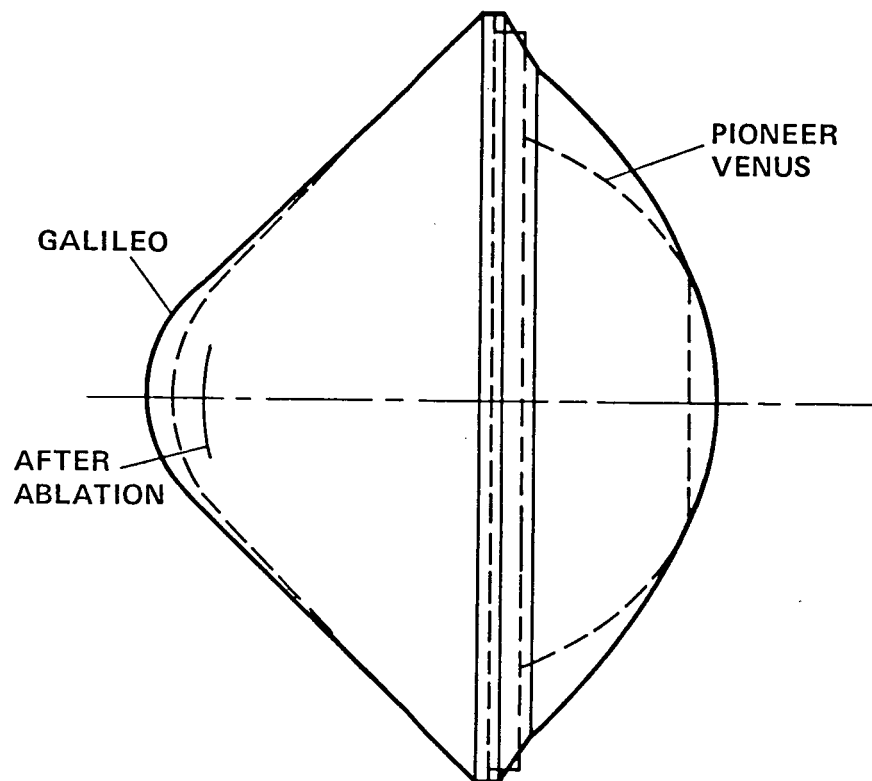


Figure 2. Comparison of Galileo with Pioneer Venus geometry

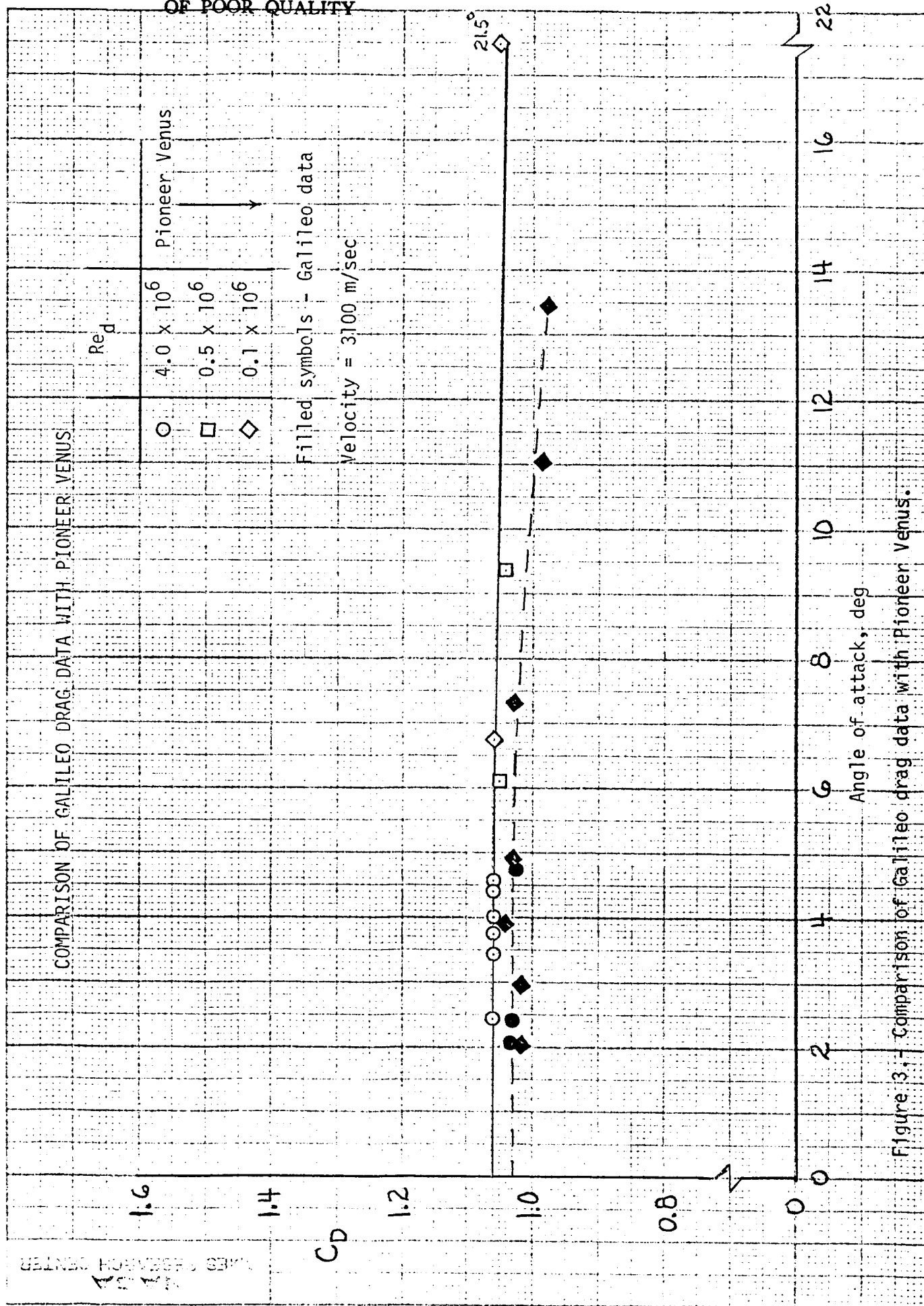


Figure 3.- Comparison of Galileo drag data with Pioneer Venus.

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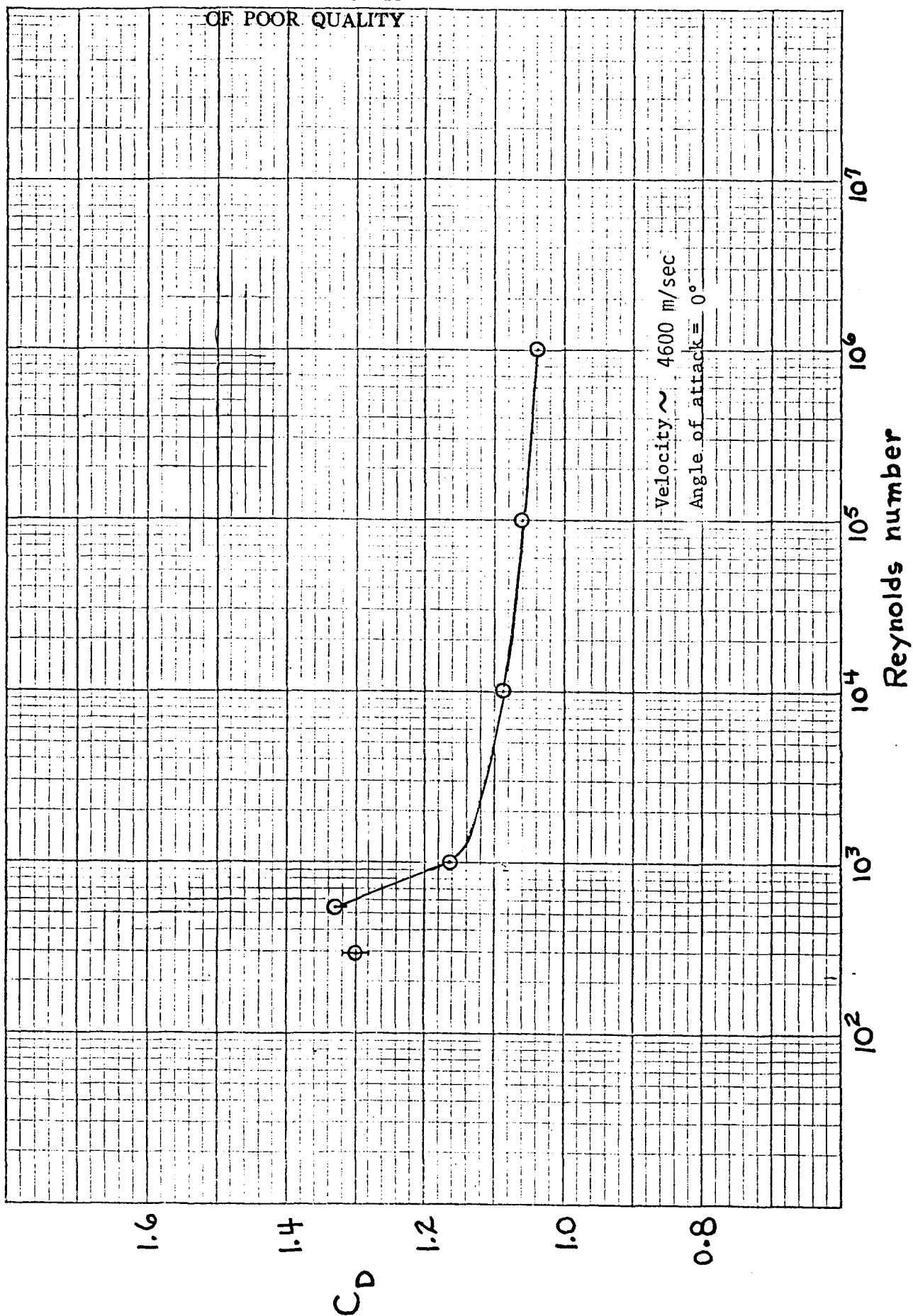


Figure 4.- Effect of Reynolds number on drag characteristics of Pioneer Venus probe vehicles